International Journal of Agricultural Science and Research (IJASR)
ISSN(P): 2250-0057; ISSN(E): 2321-0087
Vol. 5, Issue 4, Aug 2015, 331-342

OIL PALM ROOTS ADAPTATION UNDER SOIL COMPACTED BY MECHANISATION

ZURAIDAH Y, HANIFF M. H & ZULKIFLI H

Biological Research Division, Malaysian Palm Oil Board, Kuala Lumpur, Malaysia

ABSTRACT

Mechanization in oil palm plantations alters the soil physical properties, which consequently restrict the growth and function of roots. This study was carried out to evaluate the consequences of compaction due to mechanization on oil palm roots. Comparisons were made on the effects of different trailer weights on oil palm roots growth and their ability to adapt to the altered soil conditions. Roots were sampled using root auger at 0-30 cm depth at the harvesting paths and frond pile areas. The results showed that the growth of oil palm roots was altered by the mechanization treatments. A greater root biomass was observed in the control, while the treated plots showed a decreasing trend in root biomass with increasing trailer weight. The 4T trailer weight treatment had significant effects on the oil palm root development. The reduction in total root biomass in the compacted plots was compensated by higher tertiary and quaternary roots biomass. This resulted in a significant increase in root surface area for better water and nutrient uptake as compared to the control. The compaction treatments influenced the soil physical properties, which in turn affected the growth and distribution of oil palm roots.

KEYWORDS: Mechanization, Oil Palm Roots, Trailer Weight, Soil Physical Properties, Soil Compaction

INTRODUCTION

Vigorous root systems are as essential as vigorous shoots for plants to be healthy. Roots not only absorb water and minerals, but they have other important functions such as anchorage, conversion of inorganic nitrogen into organic compounds, and synthesis of growth regulators such as cytokinins and gibberellins. Both environmental and cultural conditions are expected to modify the development of oil palm roots. The roots are able to respond to changes in soil properties to some extent. The ability of roots to grow and explore the soil for water and nutrients is an important factor affecting the growth and yield of oil palm. Root elongation and proliferation are strongly affected by many physical and chemical properties of the soil. Crop growth is often constrained by poor root development, slow water infiltration and movement through the soil, and also by poor soil aeration. Soil compaction from heavy equipment can alter many characteristics of soil and plant responses may be correlated with these alterations depending on their stage of development (Trouse, 1971) and reduced rooting volume would mechanically destabilize the whole plant (Coder, 2000). Significant increase in soil density limits plant growth by physically restricting root development. They tend to grow horizontally at the upper soil layers, preventing access to the water and nutrients stored deep in the soil (Hills *et al*., 1998). Subsequently, they become more susceptible to other crop stresses such as heat, insects and diseases. Herbicide injury and root diseases such as *Pythium, Rhizoctonia* and *Fusarium* root rots can increase with increasing soil strength (Davis, 1998; Duiker, 2007). However, some plant species have a greater ability to overcome mechanical stress e.g. perennial grasses (Clark *et al.*, 2003) and those with a deep tap root system usually have the ability to penetrate deeper in compacted soils (Gill, 1971).

The root system, as well as its distribution in the soil is a crucial factor that affects fertilizer use efficiency in oil palm. Thus, the ability of roots to grow and explore the soil for water and nutrients is vital to the oil palm growth and yield. Morphologically, the oil palm root system comprises of an extensive fibrous and adventitious root system that radiates from the prominent bole (Ng *et al.*, 2003). The roots could grow vertically, either upwards or downwards, or horizontally, and maintain the same direction of growth throughout their life span, and branching angles are always very close to 90^o (Jourdan *et al*., 2000). Oil palm bears an adventitious root system with primary roots, generally about 6 to 10 mm in diameter commencing from the trunk base and bearing secondary roots of about 2 to 4 mm in diameter. The tertiary roots, about 0.7 to 1.2 mm in diameter, branching out from the secondaries, which in turn carry the quaternaries. Quaternary roots are about 0.1 to 0.3 mm in diameter, unlignified and often assumed to be the major absorbing roots (Fairhurst and Hardter, 2003; Corley and Tinker, 2003; Corley *et al.*, 1976). The total length of tertiary and quaternary roots in the soil is the most important root characteristic as they are absorbing roots that affect fertilizer use efficiency. The root biomass is largely found within 1 m of the soil surface, but tertiary and quaternary roots are found mostly in the upper 30-cm from the soil surface. Primary roots can travel up to 20 m from the base of the palm and some could even penetrate below the water table at 90 cm from the surface. (Ng *et al*., 2003; Chan, 1977).

Roots distribution varies depending on the soil qualities. Oil palm being a monocot needs a friable soil for root branching because the roots cannot expand laterally, forcing their way through impermeable material. The extent of root system may also be restricted by the occurrence of a water table and root elongation as well as proliferation is strongly affected by many physical and chemical properties of the soil (William and Hsu, 1970). Excessive soil compaction impedes root growth and the roots tend to grow horizontally.

In soils with good physical properties, the entire topsoil is well permeated with roots from an early stage of development in a plantation (Corley *et al.*, 1976). In drainage trials of oil palm in Quepos area, Costa Rica, Peralta *et al.* (1985) found considerable differences in the quantity of tertiary and quaternary roots present in the superficial layer (0-30 cm) of well and poorly aerated soils. About 82.4% of total roots were found in the superficial layer of poorly aerated soils whereas 70.6% were found in well aerated soils. It appeared that under anaerobic condition, the palm responds by producing more absorptive roots that apparently affects nutrient absorption.

Many studies have been done on the effect of mechanization on soil physical properties such as bulk density and porosity, yet relatively few have related them to root growth. Although very tedious and time consuming, root study is an important aspect of research to determine the plant response to changes in soil physical properties. This trial was carried out to evaluate the oil palm root adaptability under mechanized plantation.

MATERIALS AND METHODS

Compaction Treatments

The study was conducted in an oil palm plantation located at latitude 4^o 00' 20.96268" N and longitude of 100^o 50' 18.66199” E in Peninsular Malaysia. The soil was clayey Bernam Series soil (Typic Endoaquepts), on a flat coastal terrain and developed over marine alluvium. The treatments consisted of tractor without trailer (0T), tractor with 2 tonnes trailer weight (2T) and tractor with 4 tonnes trailer weight (4T). The tractor used for 0T and 2T was Yanmar, model US250D; and Fiatgari, model New Holland 55.56 DT was used for 4T (Zuraidah *et al*., 2015). The transportation frequency was 3 rounds (3R) monthly. There was no motorized vehicle in the control plots where fresh fruit bunches were collected using wheel barrow. Treatments were carried out in five replications and completed in six years.

Root Sampling

Destructive sampling was used for evaluating the response of oil palm roots to the treatments. Root samples were taken from the harvesting path and frond pile areas of treatment plots that were exposed to compaction of three rounds transportation frequency per month. Root sampling was done following the triangle method developed by Tailliez (1971). The triangular area between three neighboring palms was subdivided into 16 sub-triangles and root samples were obtained from the centre of each sub-triangle at 0 to 30 cm soil depth using a root auger (Eijelkamp, Netherland) with a diameter of 10 cm and a height of 15 cm (Figure 1). Therefore, a total of 480 root samples were extracted from the 5 trial blocks. Before being taken to the laboratory for analysis, the roots were first separated from the soil (Zuraidah *et al.,* 2010).

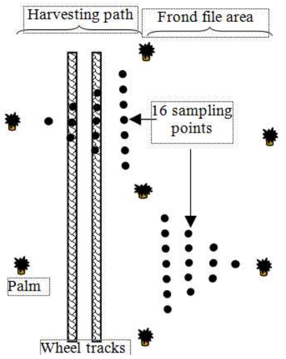


Figure 1: Schematic Diagram of Root Sampling Points

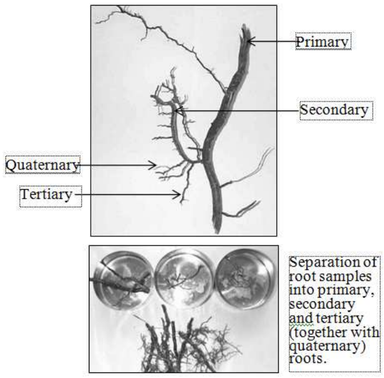


Figure 2: Separation of Oil Palm Root Samples into their Root Classes

Root Analysis

The remaining soils adhering to the roots were removed by washing with water. They were then separated according to their classes, i.e. the primary, secondary and tertiary together with quaternary roots (Figure 2). The quaternary roots were too small to be separated from the tertiaries. After separation, measurements were taken for the root length and diameter. A digital caliper was used to measure root diameter, while root length was measured indirectly using the 'intersection method' as described by Tennant (1975). Using this method, the intersections between the roots with both vertical and horizontal lines of 1-cm grid square were counted. The root length was then obtained by multiplying the total number of intersections with the conversion factor of 0.786. Assuming roots are cylindrical, surface area was calculated from the root diameter and length (Goh and Samsudin, 1993). Dry weights of roots samples were recorded after drying in the oven at 70-80 ^{o}C until constant weight.

RESULTS AND DISCUSSIONS

Oil Palm Total Root Biomass

The oil palm total root biomass was found to be affected by the compaction treatments. The control and 0T plots had a greater root biomass. With increasing trailer weights, the total root biomass in 2T and 4T plots showed a decreasing trend. It was significantly reduced by about 28% in 4T plots as compared to control. However, the reduction in 2T was not significant and there was no statistical difference in total root biomass in control and 0T (Figure 3).

Consequently, a relationship between root growth and bulk density exists as bulk density is one of the physical factors that could influence the root growth. An inverse relationship between soil bulk density and total root biomass was observed as shown in Figure 4. The reduction in root growth could be a direct consequence of increased soil mechanical

impedance due to significantly higher bulk density and lower porosity of the compacted soil caused by the trailer weight (Zuraidah *et al*., 2009). Since oil palm has a relatively shallow root system, they tend to develop less in compacted than in non-compacted fields. Compacted soils were less favourable for root elongation as they could limit the amount of soil explored by roots compared to those in the non-compacted soil (Zuraidah *et al*., 2010), but the compacted plots in this study never reached the critical levels of soil bulk density that could restrict root growth (Table 1).

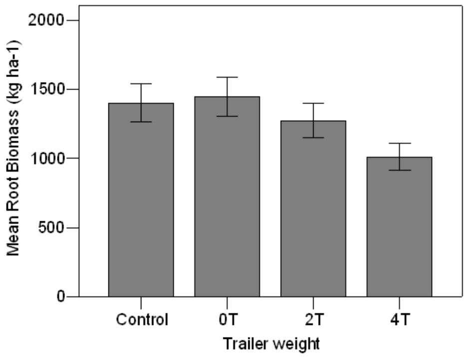


Figure 3: Total Root Biomass Per Hectare Affected by Trailer Weights

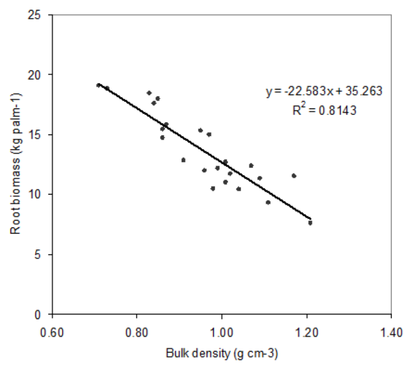


Figure 4: Root Biomass in Relation to Soil Bulk Density

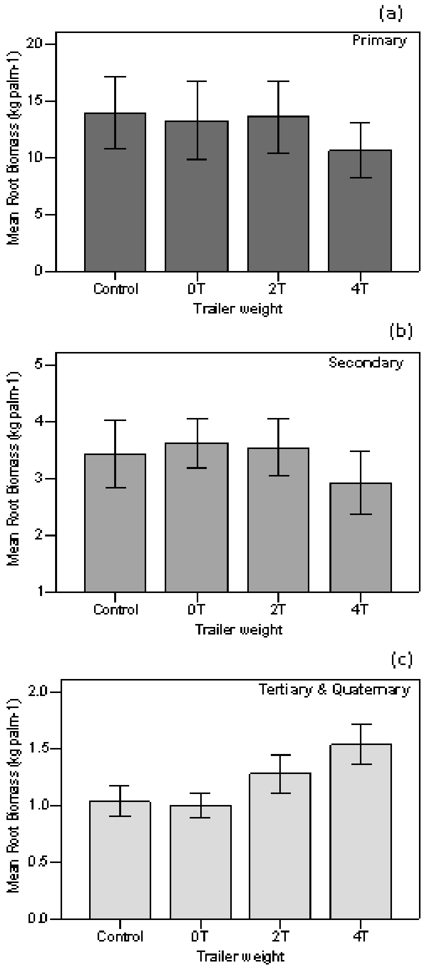
Table 1: General Relationship of Soil Bulk Density to Root Growth Based on Soil Texture (USDA, 1999) and Bulk Densities from the Study Site at Melentang Estate

Soil Texture (USDA,1999)		Bulk Densities (G Cm^{-3})		
		Ideal	Affect Root Growth	Restrict Root Growth
sands, loamy sands		< 1.60	1.69	> 1.80
sandy loams, loams		< 1.40	1.63	> 1.80
sandy clay loams, loams, clay loams		< 1.40	1.60	> 1.75
silts, silt loams		< 1.30	1.60	> 1.75
silt loams, silty clay loams		< 1.40	1.55	> 1.65
sandy clays, silty clays, some clay loams (35-45% clay)		< 1.10	1.49	> 1.58
clays (> 45% clay)		< 1.10	1.39	> 1.47
Soil texture (study site)	Treatment			
clay (50% clay)	0T	0.91		
	2T	0.94		
	4T	0.96		

Oil Palm Total Root Biomass per Palm

Although the total root biomass was lower in compacted plot, the reduction of total root biomass per palm was not significant as compared to non-compacted plots (Figure 5). However, when the values were extrapolated to kg per hectare, the compaction treatments significantly affected the total root biomass (Figure 3). Per palm basis, the control and 0T compaction treatment did not affect the growth of roots in different classes. The 2T compaction treatment did not affect the primary and secondary roots, but the tertiary and quaternary roots were significantly higher by about 23% than control [Figure 5(c)]. The 4T compaction treatment affected the growth of all root classes. The primary and secondary roots were reduced by about 31% and 18%, respectively as compared to control. On the other hand, the tertiary and quaternary roots significantly increased to 33% greater than control (Figure 5(c)). In more compacted soil, the growth of primary and

secondary roots was restricted due to higher soil bulk density and reduction of macropores. The root growth declined as roots have to exert greater force to penetrate through the soil while searching for water and nutrients. Subsequently more lateral roots were produced in order to fit into smaller soil pores.



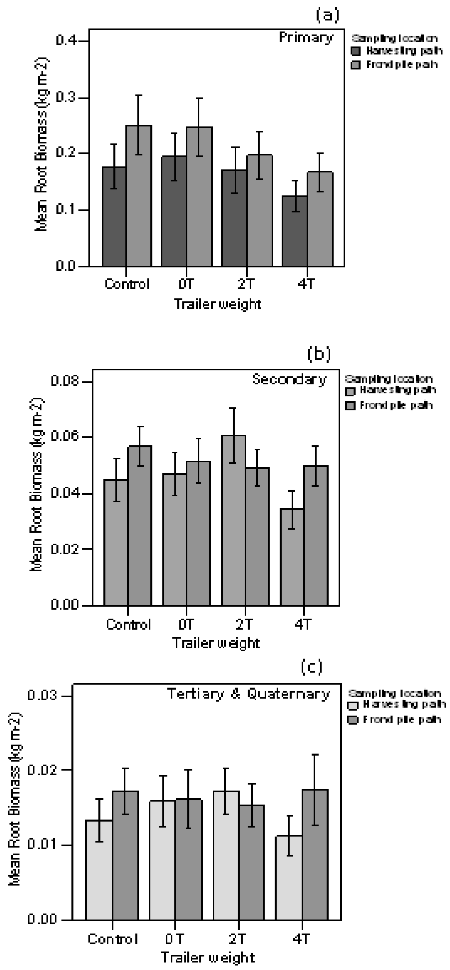


Figure 5: Oil Palm Root Biomass per Palm Affected by trailer Weight

Figure 6: Root Biomass of Primary (a), Secondary (b), Tertiary and Quaternary(c) at Different Sampling Points

Oil Palm Root Biomass at Different Sampling Point

Although not significant, generally roots of all classes were produced more at the frond pile area as compared to the harvesting path for all compaction treatments (Figure 6). The lower bulk density, higher porosity and organic matter contents present at the frond pile area provide better condition for root growth. They show preferential growth towards better conditions of water and nutrient supply in the frond pile areas (Corley and Tinker, 2003). In contrast, the quantity of roots was reduced at the harvesting path. The application of fertilizers and crop residue changes soil fertility in the respective zones of application. Thus the concentration of feeder roots is often greatest in the soil beneath the weeded circle and the frond pile area (Fairhurst and Hardter, 2003).

Oil Palm Root Biomass at Different Sampling Depths

The primary roots were produced significantly higher at the lower layer of 10 to 30 cm soil horizon [Figure 7(a)].

Primary roots are adventitious and extend either downwards from the base of the palm or outwards in a more or less horizontal direction. Vertically descending primary roots provide anchorage, while those descending at various angles provide a framework supporting the secondary, tertiary and quaternary roots (Corley and Tinker, 2003; Fairhurst and Hardter, 2003). Therefore there were fewer primaries at the soil surface of 0-10 cm depth.

The secondary roots were distributed evenly throughout the soil profile. There was no significant different of secondary roots produced between soil layers [Figure 7(b)]. Secondary roots branch at right angles to the primary roots. They grow both downwards and upwards. The ascending secondary roots generally reach the surface of the soil and then turn horizontally, while the ascending ones may penetrate to a depth of several metres (Corley and Tinker, 2003 ; Fairhurst and Hardter, 2003). Hence, they were well distributed in the soil profile.

The upper layer of 0 to 10 cm was well colonised by the tertiary and quaternary roots [Figure 7(c)]. Tertiary roots arise at right angles to secondary roots. Unlignified quaternary roots arise at right angles to tertiary roots. They show no preferred direction of growth (Corley and Tinker, 2003; Fairhurst and Hardter, 2003). As feeder roots, they show preferential growth in fertile soil usually found beneath the weeded circle and the frond piles.

Oil Palm Root Length Density

The most useful root parameter is root length density distribution around the palm. It is the ability of roots to absorb nutrients and water that is important, which is related to the total length of root per unit volume of soil. Diffusion theory has shown that that root length is more important than either root mass or volume for the uptake process for most ions and water, because of the restriction imposed by the soil onion diffusion and water capillary movement (Corley and Tinker, 2003). Roots growing into compacted soil must displace soil particles; hence the rate of elongation decreases as soil strength increases.

The primary and secondary root length density were unaffected by the 0T and 2T compaction treatments. However, the 4T trailer weight significantly reduced root length density of the primary and secondary roots by about 23% and 19%, respectively, compared with the control [Figures 8(a) and 8(b)]. In contrast, increased soil compactness resulted in a corresponding increase in the length density of the tertiary and quaternary roots [Figure 8(c)]. Thus, with increasing trailer weight, palms in the compacted soils produced less primary and secondary roots but compensated by producing longer tertiary and quaternary roots for better uptake of water and nutrients.

Root length density was greater in the 0T and 2T plots, suggesting that the primary roots proliferate better in less compacted soils. The inhibition of root elongation was due to higher bulk density in 4T plots. As soil strength increases, root elongation rate decreases due to the increasing resistance of the soil particles to displacement. Researchers have found that the root elongation rate or root length was inversely proportional to mechanical impedance (Bennie, 1996; Jungk, 1996).

Theoretically, the root length density of tertiary and quaternary should also be lower with increasing trailer weight due to higher soil bulk density. However, increase in soil compactness resulted in a corresponding increase in the length density of tertiary and quaternary roots. Palms in compacted soils produced less primary and secondary roots but compensated by producing longer tertiary and quaternary roots with increasing trailer weight (Figure 8) for better uptake of water and nutrients. The results suggested that the shorter root length density requires the primary and secondary roots to maintain a higher than normal uptake rate of nutrients and water per unit root length in order to keep pace with the high

demand, they produce longer tertiary and quaternary roots. Greater root length in compacted soils could also be in response to better soil available water as roots tend to proliferate more in soil regions with high water content. As reported by Michael and Quisenberry (1993), when moisture was adequate, higher amounts of nutrients were available, hence resulting in greater root elongation and proliferation.

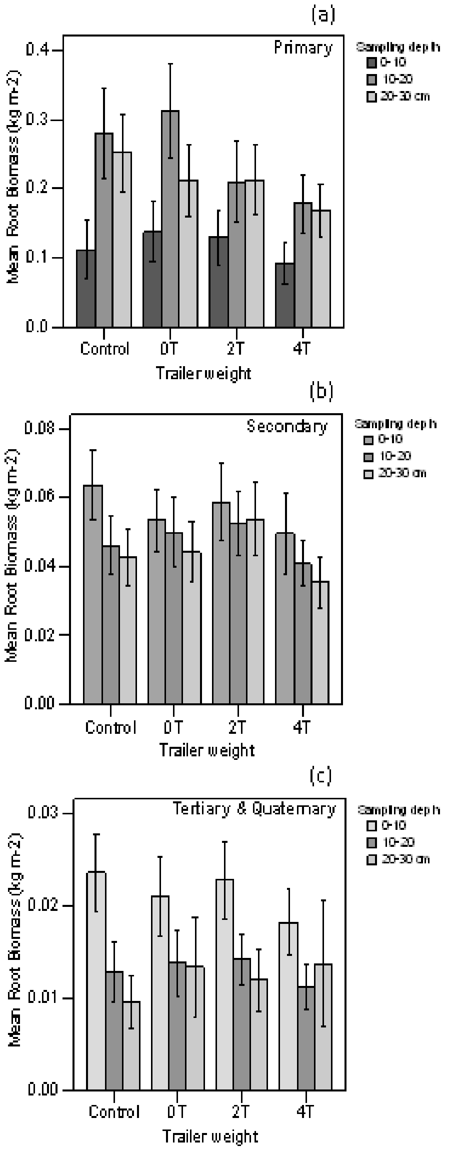


Figure 7: Root Biomass of Primary (a) Secondary (b), Tertiary and Quaternary (c) at Different Sampling Depths

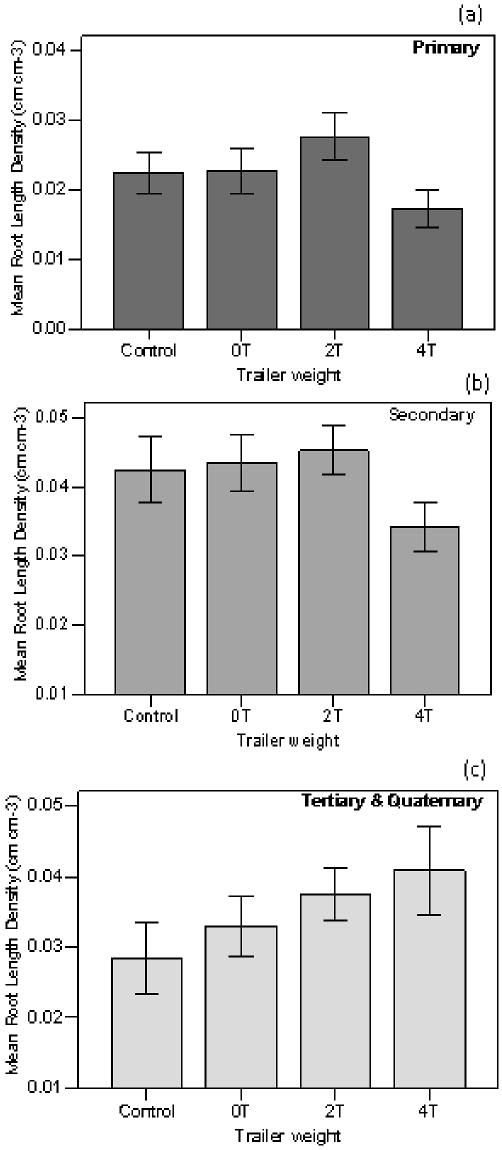


Figure 8: Root Length Density of Primary (a), Secondary (b), Tertiary and Quaternary (c) Affected by Trailer Weight

Oil Palm Root Diameter

The primary root diameter was unaffected by the 0T and 2T compaction treatments. However, the 4T trailer weight had significantly increased the root diameter of the primaries by about 10% as compared to control [Figure 9(a)]. The inhibition of root elongation due to higher bulk density in 4T plots was compensated by an increase in root diameter in order to generate more energy to penetrate the soil. Root diameter was smaller in the other treatment plots, suggesting that

the primary roots proliferate better in less compacted soils.

The diameter of secondary roots was significantly increased by about 11% in compacted plots. On the other hand, the secondary roots in control plots were found to be significantly thinner as they can easily explore the non-compacted soil. There was no significant difference in the diameter of the secondary roots in the other treatment plots [Figure 9(b)]. The diameter of secondary roots tends to increase with slight increase in soil compactness although their length density was only affected by the heaviest trailer weight. This indicates that the secondary roots could generate more energy to penetrate the soil farther compared to the primaries. Increased soil compactness of the 2T and 4T plots resulted in a corresponding increase in the diameter of the tertiary and quaternary roots by 16% compared with the control [Figure 9(c)].

Root systems are generally very elastic and adapt morphologically in their response to adverse physical conditions. Inhibition of root elongation due to mechanical impedance may be compensated by an increase in root diameter or branching of the root system. Generally, when primary root length decreases, root diameter increases, and the number of lateral roots also increases. Bennie (1996) and Jungk (1996) found that root diameter was directly proportional to mechanical impedance. Hence, shorter and larger roots were produced in compacted soil. These changes appear to enable plants to adapt to adverse soil conditions. Plants with larger diameter roots tend to better penetrate soils of high mechanical resistance. Study by Mosena and Dillenburg (2004) on Brazilian pine found that higher values of soil bulk density were associated with a shorter and thicker tap root although the growth of lateral roots and shoots remained unaffected at earlier stage.

Roots grow through the soil either by growing through pores larger than their own diameter, or by enlarging pores smaller than their own diameter. This indicates that the secondary roots could generate more energy to penetrate the soil farther as compared to the primary roots.

With compaction, soil porosity decreased and pore space diameters become smaller. Once soil pore diameters are less than the diameter of main root tips, root morphological changes could occur. The thickening of roots growing in compacted soil indicates the absence of pores with diameter equal to or larger than the roots. Root becomes thicker to exert more force to squeeze into diminished sized pores. As roots thicken, growth slows down and more laterals are generated of various diameters that are small enough to fit into pore sizes of the compacted soil (Coder, 1998 ; Lipiec *et al.*, 2003).

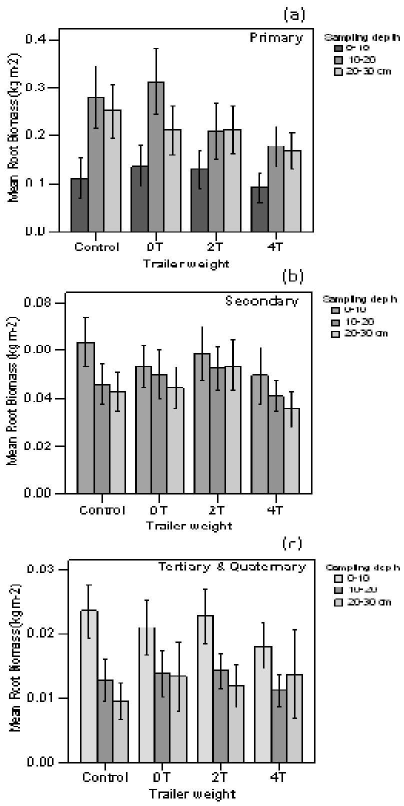
Increase in soil compactness in 2T and 4T plots resulted in a corresponding increase in diameter of tertiary and quaternary roots. Palms in compacted soils produced less primary and secondary roots but compensated by producing longer and thicker tertiary and quaternary roots [Figures 8(c) and 9(c)] for better uptake of water and nutrients.

Oil Palm Root Surface Area

The tertiary and quaternary roots are considered to be the main absorbing parts of the oil palm root system. The ability of roots to absorb nutrients and water is related to the surface area of root per unit volume of soil. Water and nutrients uptake by plants has been shown to be a direct function of root surface area (Goh and Samsudin, 1993). Therefore, the following discussions only involve the surface area of tertiary and quaternary roots for evaluating the absorbing properties of the oil palm root system.

Assuming the roots were cylindrical, the surface area was computed using the root length and diameters (Goh and Samsudin, 1993). Soil compaction increased the root length and diameter, hence resulting in increased surface area of the tertiary and quaternary roots for better water and nutrient uptake. The root surface area increased significantly with

increasing trailer weight and the 4T treatment increased root surface by 54% as compared to control (Figure 10). Increase in surface area of the tertiary and quaternary roots could facilitate a higher nutrients uptake contributing to higher yield.



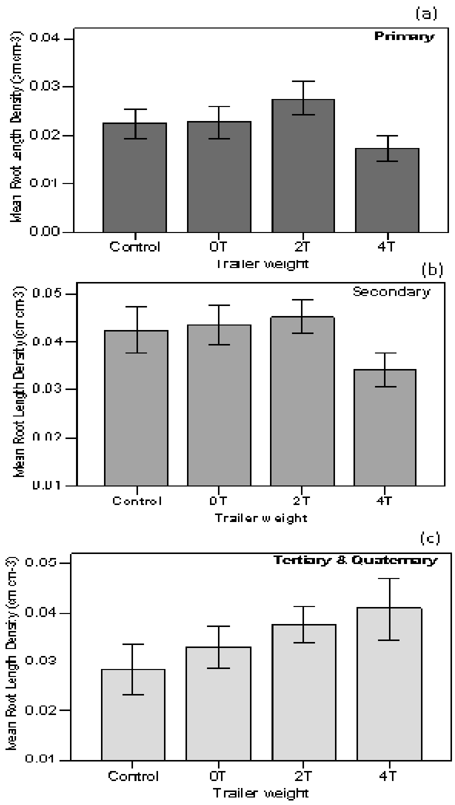


Figure 9: Root Diameter of Primary (a), Secondary (b), Tertiary and Quaternary (c) Affected by Trailer Weight

Figure 10: Surface Area of Tertiary and Quaternary Roots Affected by Trailer Weight

CONCLUSIONS

Oil palm root system is able to adapt to changes in soil physical conditions. Inhibition of root elongation due to mechanical impedance was compensated by an increase in root diameter or branching of the root system. Root elongation and proliferation are strongly affected by the physical properties of the soil. Soil compaction increased the root length and diameter, thereby resulting in an increased surface area of the tertiary and quaternary roots. Further study is needed to determine whether the roots behave in the same manner in other soil with different textural classification.

ACKNOWLEDGEMENTS

The authors would like to thank the Director-General of MPOB for permission to publish this paper. Special gratitude also goes to all members of Agronomy and Geospatial Technology Unit, MPOB for their excellent help.

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